THE EFFECTIVENESS OF MINE DRAINAGE POLLUTION CONTROL MEASURES ELKINS, WEST VIRGINIA

Ronald D. Hill

Mine Drainage Pollution Control Activities
Federal Water Pollution Control Administration
Cincinnati, Ohio

INTRODUCTION

The seriousness of water pollution by acid drainage from coal mines is highlighted by the following figures: In Appalachia(1) during 1966, more than 6,000 tons of acidity per day were discharged from active and inactive mines, polluting more than 10,000 miles of streams.

In 1962, an authoritative report, "Acid Mine Drainage"(2) was issued by the Committee of Public Works of the U. S. House of Representatives. Recognizing the extent of the problem, the report pointed out that elimination of this form of pollution would restore vast quantities of water for municipal and industrial use, propagation of fish, aquatic life, and wildlife, recreational purposes, and other uses. After pointing out that most of the various methods developed to abate acid mine drainage had been abandoned because of high costs and technical failure in field applications, the Committee concluded that mine sealing was the most promising method.

The report recommended (1) a sealing program directed at sealing abandoned mine shafts and other drainage openings, (2) a stepped-up research program by federal, state, and interstate organizations to develop other measures, and (3) a stream and acid flow regulation program to be employed where sealing or other methods are unable to sufficiently reduce the acid content of the stream to meet water quality requirements for all legitimate purposes.

The report also called for a demonstration program to evaluate mine sealing procedures and results, suggesting that the work be done in "three appropriate watersheds containing between 50 and 100 abandoned coal mines each from which acid water is now draining." Funds for the demonstration grant, $5 million, were authorized by Congress in 1964.

The work was to be under the direction of the Water Supply and Pollution Control Program of the Department of Health, Education, and Welfare, the forerunner of the Federal Water Pollution Control Administration which later was transferred to the U. S. Department of the Interior. Other participating agencies were the U. S. Bureau of Mines, U. S. Geological Survey, U. S. Bureau of Sport Fisheries and Wildlife(2), and West Virginia agencies in charge of mining, water pollution, and reclamation.

In March 1964, the first demonstration project site was selected in the Roaring Creek-Grassy Run watershed near Elkins, West Virginia. The areas contained one large drift mine (3,000 acres) and a number of smaller underground mines which had been extensively strip mined along the out-crop. The surface mine intercepted runoff and directed it into the underground mine, which in turn flushed more mine drainage from the underground workings. These streams were contributing 12 tons per day of acidity to the Tygart River. Chemical characteristics of the two streams are presented in Table I.

The demonstration project was carried out in three phases: (1) site, (2) mine sealing, regrading, and revegetation, and (3) project evaluation. Phase 1, begun in March, 1964 and completed in July, 1966, was devoted to water quality surveillance (FWPCA); stream gaging (USGS): surface mapping, investigation of mine conditions, and design control measures and reclamation planning (USBM); securing land permits (W. Va.), and award the construction contract (FWPCA, USBM). Sealing of the mines and concurrent reclamation measures (Phase 2) were begun in July 1966 and completed in September 1967. Disturbed areas were vegetated in the spring of 1968. Phase 3, evaluation of the effectiveness of mine sealing and reclamation measures is continuing.

Table I
Water Quality Characteristics[a]

	Grassy Run		Roaring Creek	
	mg/l	Tons/day	mg/l	Tons/day
pH[b]	2.55	___	3.3	___
Acidity, (Hot), $CaCO_3$	656	10.6	110	1.8
Iron, Total	110	1.8	5	0.08
Iron, Ferrous	4	0.06	1	0.01
Sulfate	992	16.0	168	2.7
Hardness, $CaCO_3$	446	7.2	99	1.6
Calcium, $CaCO_3$	293	4.7	76	1.2
Aluminum	38	0.6	12	0.2
Specific Conductance[c]	1,723	___	530	___
Flow[d]	6	___	40	___

a - Average values for period March 1964 to June 1966
b - Unit not mg/l, median value
c - Units - micromhos per cm
d - Units - cfs

CONTROL MEASURES

The control measures planned were as follows:

1. Air sealing of the underground mine: Since oxygen was felt to be necessary for the oxidation of pyrite and the production of iron and acidity, preventing oxygen from reaching the pyrite should reduce or eliminate acid pollution. Air sealing was to be accomplished by filling all bore holes, subsidence holes, and other air passages into the mine. "Wet" mine seals, which allow water to leave the mine, but prevent air from entering, were to be constructed at all openings discharging water.

2. Water diversion: Since water is the transport media for carrying acid and iron from the mining environment, reducing the amount of water passing through a surface or underground mine will reduce the amount of pollution. To prevent water from entering underground mines, subsidence holes were filled, streams were rechanneled away from mines, and "dry" seals, a solid seal through which water could not pass, were constructed in mine portals.

3. Burying of acid-producing spoils and refuse: Since these materials were major contributors to pollution they were buried in surface mine pits.

4. Surface mine reclamation: Although surface mines were to be regraded primarily to prevent water from entering the underground mine, regrading also reduces the time that water is in contact with acid-producing material in the surface mine itself. During regrading attempts were made to bury the highly acid material.

5. Revegetation: All disturbed areas were revegetated to prevent erosion and stablize the backfills.

Both "wet" and "dry" seals were constructed from concrete block and coated with urethane foam on both sides to protect the block from acid attack. The mine opening was timbered on both sides of the seal in order to keep the weight of the roof off the seal. Dry seals were composed of one wall, while the wet seals had three walls; one wall was solid except that two blocks were removed from the bottom, the inner wall was approximately 12 feet from the seal and 2½ feet high, and the outer wall was 5 feet from the seal and 2½ feet high. The latter two walls formed a pool which prevented air from entering the mine. Clay seals were used in areas where the highwall was badly fractured and deep mine workings lay behind the wall. For this type of seal, clay was compacted against the highwall to a height well above the underground mine workings.

Three types of backfills were used on the surface mines - contour, pasture, and swallow-tail. For a contour backfill, the spoil was graded back to as close as possible to the original contour of the land. Usually the top of the highwall was pushed down to complete the backfill. In constructing the pasture backfill, the spoil was graded to form a small slope away from the highwall and the highwall was left standing. The pasture type backfill was used when the highwall was sound. The swallow-tail backfill was similar to the pasture backfill except that in the swallow-tail, a waterway was constructed paralled to the highwall. The waterway was located away from the highwall and finial cut. Where possible, soil low in acidity was hauled in and placed on top of the backfill to facilitate revegetation and reduce acid production. Most of the subsidence holes within 100 feet of the highwall were filled with soil during the backfilling operation.

The construction contract for the reclamation work, except revegetation and the filling of subsidence holes located over 100 feet from the highwall, was entered into on June 30, 1966. Because of the many unknowns that might be encountered in working with abandoned mines, the contract was cost-plus-fixed-fee. Estimated construction cost was $1,640,362. Work begun on the south half of the major mine (3,000 acres) dealt primarily with water diversion, surface reclamation and some air sealing. By mid-1967, it became apparent that the cost for the entire project would exceed the original estimates. A decision was made to complete only the south half of the mine to conserve funds. No further work was done on the north half. This change in plans meant that the major mine would not be air sealed, however, a small isolated mine had been sealed and was available for evaluation. Thus, the project as curtailed would give information on the effectiveness of water diversion and surface mine reclamation on the south half of the major mine and the effectiveness of air sealing and water diversion on a smaller mine.

In the spring of 1968, approximately 700 acres of land disturbed during reclamation were revegetated. The most up-to-date technology was used in the revegetation program. Soil samples were taken as a guide to the fertilizer and lime requirements and for choosing the best type vegetation. The entire area was planted to grass for quick erosion control which reduced acid water drainage. Hydroseeding was used in difficult areas to assure establishment of grass. Trees were planted on the steeper slopes and the more toxic areas for long term erosion control. A summary of the reclamation and revegetation work is presented in Table II.

UNIT COST

The final determination of the unit cost for the various control measures has not been made; however, some preliminary data are available. The cost for building masonry mine seals ranged between $2,000 and $6,000 per seal; clay seals averaged $88.00. This cost included clean-up of mine opening, temporary and permanent timbering, concrete footers, concrete block walls, urethane foam coating, portal, all equipment, direct labor, 75 percent overhead, and 6 percent G and A. A preliminary cost estimate for earth moving was $0.41 per cubic yard. This cost, derived by subtracting the cost of the seals from the total cost, is unrealistic, higher than the actual earthmoving cost.

A complete analysis of the unit cost for revegetation was made and is presented in Table III.

RESULTS

This reclamation work was completed, except for revegetation, in the fall of 1967, thus a little over a year's data are available for evaluating the effectiveness of the control measures.

MINE SEALING

As noted earlier, a small isolated mine was completely air sealed. This mine was a combination of underground and surface operations. Two seams had been surface mined (78 acres) the seam in which the underground mine was located and the seam above the deep mine. The size of the underground mine is unknown, but it is estimated to cover only a few acres, as the mine was never developed.

The surface mines were regraded to facilitate rapid runoff. A pasture type backfill was used on the upper areas and a contour backfill on the lower. There were two portals into the underground mine. One portal was sealed by packing clay into the opening and a "wet" seal was installed in the second opening to allow water to discharge.

Table IV shows the air quality within the mine and the quality of the discharge. Within two months after the mine had been sealed, the oxygen content of the mine atmosphere had been reduced to 9.1 percent. Since that time, the oxygen content has varied between 7.0 and 10.8 percent, indicating that air has access to the mine. The presence of oxygen in the mine may be due to movement of air through the overburden as a result of barometic changes.

The acidity concentration of the discharge decreased to a value less than any obtained in the 44 months of pre-construction monitoring in less than a month after sealing was completed. The lowest acidity value during pre-construction was 438 mg/l, while the highest post-sealing value has been 388 mg/l. Over the long-term, the acidity is expected to continue to decrease, but at a much slower rate than the initial decrease. For example, the acidity in November 1968 was 247 mg/l compared to 388 mg/l in November 1967. A similar large initial decrease in acidity followed by a smaller decrease has also been observed by Moebs.[4] No explanation for the initial decrease has been developed; however, it would not appear to be due to the reduction of the oxygen content within the mine because the acid being discharged at any given time is an indication of the pyrite oxidation at some previous time. Thus, a lag occurs between the time the oxidation rate of pyrite is reduced and the time this reduced rate will be noted in the discharge. During the period of initial decrease the oxygen content was just beginning to decrease and no lag period had occurred. Shumate and Smith[5] found this lag to be several months. The long-term decrease in acidity is probably an indication of reduced oxidation of pyrite.

The total iron content of the discharge has decreased very little, if any. Approximately 90 percent of the iron before sealing was in the ferric form and after a year the ferrous content has not increased, indicating that sufficient oxygen is available within the mine to oxidize the ferrous iron resulting from pyrite oxidation. At the low pH's occurring in the discharge, ferric iron is highly soluble, therefore, the opportunity for the iron to precipitate within the mine is small.

The sulfate, a product of pyrite oxidation, has decreased since the mine was sealed.

In many months the sulfate content was less than the minimum concentration observed before sealing. This reduction in sulfate may be another indication that the rate of pyrite oxidation has decreased.

In summary, the data from this mine seal indicate that some reduction in pyrite oxidation may be occurring, however, the water quality is still extremely poor.

Although the major mine in the project area was not completely sealed against air the discharges from the 11 "wet" seals in that mine are still being monitored. Ten of these discharges have shown no significant changes in water quality. The eleventh has shown improvement as given in Table V. This "wet" seal is located in a mine portal. In general, the mine drainage in this area is away from the mine portal; however, there is a localized dip in the coal and the drainage from a small area drains out the portal.

The pH of this mine seal discharge has increased, reaching as high as 6.4 in September. The acidity, total iron, and sulfate concentration show some decreasing trends. No air samples have been collected from the mine, therefore, data are not available to determine if the oxygen content has decreased. It was originally felt that this portion of the mine was not air sealed since there are many known holes into the mine. However, there is a chance that due to subsidence within the mine this section is isolated from the major mines and thus air sealed. Air samples are to be collected to check this premise.

Table II
Reclamation Work Performed

Reclamation	
Land disturbed	710 acres
Surface mines reclaimed	12.5 miles
Backfill, total	3,600,000 cubic yards
Backfill, compacted	61,269 cubic yards
Subsidence holes filled	450
Mine seal, dry	43
Mine seal, wet	12
Mine seal, clay	41
Mine seal, other	5

Revegetation	
Total	710 acres
Grass only	322 acres
Hydroseed only	16 acres
Trees only	57 acres
Hydroseed grass and trees	195 acres
Grass and trees	120 acres

SURFACE MINE RECLAMATION

The effectiveness of surface mine reclamation on water quality was evaluated by collecting samples of runoff during wet periods and by monitoring the streams to which the surface mines discharge. Six areas were isolated and evaluated.

Site RT 8F-1. This sampling point was used to measure the effect of reclamation on 49 acres of surface mines. One underground mine discharge remains in the area. The opening has been sealed. As seen in Table VI, the acidity has varied considerably since the reclamation was completed. With the exception of December 1967, the acidity has been less than the average for the pre-reclamation period, and during five months the acidity level was less than the minimum value obtained prior to reclamation.

The pH has been greater during post-reclamation and the sulfate has a decreasing trend. In general, the water shows improvement, however, it has not recovered to its natural state. This area was discharging 59 pounds per day of acid in September 1966 and in September 1968 was discharging 38 pounds per day, a decrease of 35 percent. The high acidity in December 1967 was due to a flushing of material from the underground mine.

Site RT 9-2. This sampling point was used to measure the effect of reclamation on 160 acres of surface mines. One underground mine discharge is in the watershed, however, its contribution of mine drainage is minor. The data collected for the watershed are presented in Table VII. The acidity since reclamation has been less than the mean concentration during pre-reclamation. Even during the dry months of July, August, and September when the concentration is the greatest, the water had a lower acidity than the mean during pre-reclamation. The sulfate concentration with the exception of two months, has been less than the average for pre-reclamation. The pH has been somewhat higher, while the total iron concentration shows only marginal improvement. The acid load during the project from this area for the month of October is given in Table VIII. The data show a decrease in load after reclamation.

Site RT 9-23. This sampling point was used to measure the effect of reclamation of 256 acres of surface mines. One minor underground mine discharge is located in the area. As seen in Table IX, the acidity and sulfate concentration has been less after reclamation than the mean value before reclamation, except during September 1968 for acidity and August and September for sulfate. These high concentrations occurred during a very low flow period and it is questionable if the acidity was due to surface mines. The pH was greater than the pre-reclamation value in all but one month, again the low flow period. A comparison of the loads for October before and after reclamation is presented in Table X. A reduction in the acid load can be noted.

Site RT 6-20. This sampling point was used to measure the effect of reclamation on 45 acres of surface mines. Two large underground mine discharges are located in the watershed. In Table XI, the data collected at this site are reported.

These data indicate that there has been no improvement in the water; if anything, the water is worse. Upon investigating the source of the acid pollution, it was found that before reclamation 24 to 50 percent of the acid load was from the underground mines. After surface mine reclamation, the underground mines are contributing 75 percent of the acid load. It appears, therefore, that some benefits have occurred from surface mine reclamation.

Site RT 6-21. This site is located at the mouth of Kittle Run. A total of 140 acres of surface mines were reclaimed. Two major underground mine discharges are located in the watershed. The streambed of Kittle Run was completely destroyed during surface mining and a large portion of the runoff and the discharge from an underground mine were diverted into another underground mine. During reclamation the stream channel was reestablished, therefore, more water should be passing Sample Site RT 6-21, however, to date this has not occurred. In Table XII, the data collected at this site

Table III
Cost of Revegetation[a]

	Dollars Per Acre		
	Maximum	Minimum	Average
Conventional Grass[b]	462.08	71.13	165.22
Hydroseeding Only[c]	370.72	238.60	323.43
Trees Only[d]	194.76	55.02	106.73
Hydroseeding and Trees[e]	537.06	362.95	429.40
Conventional Grass and Trees[f]	380.53	204.47	230.56

a - Cost includes labor, equipment, materials, and overhead
b - Fertilizer (0.5 ton/acre of 10-10-10), lime (2 - 4 tons/acre) applied from truck, grass planted by seeder box.
c - Lime (2-4 tons/acre) spread from truck or from farm type fertilizer spreader, hydraulic application of grass seed, fertilizer (0.5 ton/acre of 10-10-10) and organic mulch (1 ton/acre).
d - Hand planted (900 - 1,000/acre).
e - Hydroseeding plus hand planted trees (900 - 1,000/acre).
f - Conventional grass as in b, plus hand planted trees (900 - 1,000/acre).

Table IV
Effectiveness of Mine Seal - Area 24

	Oxygen[e] Within Mine, %	Acidity (Hot) $CaCO_3$, mg/l	pH	Iron, mg/l	Sulfate, mg/l
Before Sealing[a] (Mean)	___	591 (65)[b]	2.8[c]	93 (25)[b]	1035 (155)[b]
Minimum	___	438	3.1[d]	48	710
After Sealing					
Oct. 67	___	388	3.1	86	835
Nov. 67	9.1	365	3.2	83	770
Dec. 67	___	325	3.2	87	785
Jan. 68	7.8	315	3.1	75	655
Feb. 68	___	328	3.2	69	700
March 68	8.8	332	3.2	77	703
April 68	___	277	3.3	60	625
May 68	10.8	344	3.3	64	620
June 68	___	382	3.0	81	860
July 68	7.0	354	3.2	73	780
Aug. 68	___	318	3.2	70	665
Sept. 68	___	360	3.0	74	680
Oct. 68	7.2	279	3.2	74	630
Nov. 68	7.6	247	3.2	78	660

a - March 1964 - August 1967
b - Number in parenthesis is standard deviation
c - Median value
d - Maximum value
e - Data collected by U. S. Bureau of Mines

Table V
Effectiveness of Mine Seal - Area 44

	Acidity (Hot) $CaCO_3$ mg/l	pH	Iron Total mg/l	Sulfate mg/l
Before Sealing[a] (Mean)	39	3.6[b]	1.1	214
Minimum	17	4.0[c]	0.3	160
After Sealing				
Oct. 67	20	3.9	0.3	230
Nov. 67	7	3.9	0.7	205
Dec. 67	40	4.0	0.6	207
Jan. 68	31	3.9	0.5	215
Feb. 68	28	3.9	0.3	215
March 68	20	4.2	1.5	140
April 68	8	4.7	0.5	81
May 68	12	5.2	0.2	120
June 68	0	5.2	2.5	156
July 68	21	4.2	0.8	180
Aug. 68	0	6.1	2.0	145
Sept. 68	17	6.4	0.9	160
Oct. 68	4	5.0	0.6	115
Nov. 68	0	5.8	0.7	96

a. Mean of 25 samples collected between March 1965 and November 1966
b. Median value
c. Maximum value

Table VI
Effect of Surface Mine Reclamation in Watershed RT 8F-1

	Acidity (Hot) $CaCO_3$ mg/l	pH	Iron Total mg/l	Sulfate mg/l
Before Reclamation (Mean)	199	3.0[a]	19	290
Minimum Value	73	3.4[b]	4	140
After Reclamation				
Oct. 67	107	3.4	28	220
Nov. 67	145	3.4	19	220
Dec. 67	921[c]	3.4	20	215
Jan. 68	38	4.8	6	78
Feb. 68	111	3.5	14	180
March 68	95	3.3	17	190
April 68	54	3.9	8	112
May 68	71	3.8	14	140
June 68	83	3.6	12	185
July 68	27	4.1	0.8	190
Aug. 68	135	3.5	13	175
Sept. 68	89	3.5	10	150
Oct. 68	55	3.7	8	155
Nov. 68	37	4.1	3	135

a. Median value
b. Maximum value
c. A flush of mine drainage from the deep mine occurred

Table VII
Effect of Surface Mine Reclamation in Watershed RT 9-2

	Acidity (Hot) $CaCO_3$ mg/l	pH	Iron Total mg/l	Sulfate mg/l
Before Reclamation (Mean)[c]	178	3.3[a]	5.2	313
Minimum Value	79	4.3[b]	1.9	48
After Reclamation				
Oct. 67	73	3.6	4.9	180
Nov. 67	68	3.6	5.4	175
Dec. 67	69	3.8	5.4	195
Jan. 68	74	3.7	3.2	220
Feb. 68	111	3.7	7.4	360
March 68	95	3.7	5.5	220
April 68	56	3.9	1.9	135
May 68	62	3.9	2.5	135
June 68	73	3.8	2.6	225
July 68	125	3.5	4.3	210
Aug. 68	105	3.5	3.4	220
Sept. 68	141	3.4	4.5	335
Oct. 68	74	3.6	4.1	240
Nov. 68	49	3.7	2.5	190

a. Median value
b. Maximum value
c. March 1964 to September 1967

Table VIII
Pollution Load from Area RT 9-2

	Flow cfs	Acidity (Hot) mg/l	Acid lbs/day	Rainfall Inches
Before Reclamation				
Oct. 65	0.226	241	293	1.43
Oct. 66	0.895	212	2,165	2.63
After Reclamation				
Oct. 67	0.67	73	263	3.33
Oct. 68	0.14	74	56	4.04

Table IX
Effect of Surface Mine Reclamation in Watershed RT 9-23

	Acidity (Hot) $CaCO_3$ mg/l	pH	Iron Total mg/l	Sulfate mg/l
Before Reclamation (Mean)[c]	178	3.3[a]	5.5	313
Minimum Value	79	4.5[b]	1.3	48
After Reclamation				
Oct. 67	40	4.1	1.5	47
Nov. 67	26	4.1	2.3	44
Dec. 67	34	4.0	5.0	62
Jan. 68	38	4.0	3.1	57
Feb. 68	43	4.0	3.4	54
March 68	49	4.0	4.7	68
April 68	25	4.1	1.2	36
May 68	22	4.3	1.1	57
June 68	35	4.0	0.7	37
July 68	116	3.6	6.6	190
Aug. 68	127	3.5	11.4	450
Sept. 68	446	3.2	15.9	340
Oct. 68	87	3.6	8.8	205
Nov. 68	44	3.9	2.9	119

a. Median value
b. Maximum value
c. March 1946 to September 1967

Table X
Pollution Load from Area RT 9-23

	Flow cfs	Acidity (Hot) $CaCO_3$ mg/l	Acid lbs/day	Rainfall Inches
Before Reclamation				
Oct. 64	0.7	191	720	2.00
Oct. 65	0.4	233	502	1.43
Oct. 66	4.7	87	2,203	2.63
After Reclamation				
Oct. 67	6.2	40	1,336	3.33
Oct. 68	1.22	87	572	4.04

are presented. The data show a small trend toward improvement of the water quality. The amount of improvement that can be expected at this site is limited by the underground discharges. Currently the deep mine discharges are contributing 70 to 80 percent of the acid. For example, on June 4, 1968, 4,320 pounds of the 6,278 pounds of acid per day flowing down Kittle Run originated at the two deep mine discharges.

Site RT 6-19. This site was chosen to measure the effect of reclamation on nine acres of surface mines. As shown in Table XIII, the runoff from this area has shown marked improvement since reclamation. Part of the increase in pH and decrease in acidity is due to the lime applied to the watershed as part of the revegetation program.

Table XI
Effect of Surface Mine Reclamation in Watershed RT 6-20

	Before Reclamation	First Eleven Months After Reclamation
pH (median)	2.7	2.9
Acidity, mg/l, $CaCO_3$	487	550
Total Iron, mg/l	91	130
Sulfate, mg/l	616	630

Table XII
Effect of Surface Mine Reclamation in Watershed RT 6-21

	Before Reclamation	First Eleven Months After Reclamation
pH (median)	2.5	2.8
Acidity, mg/l, $CaCO_3$	1,554	1,107
Total Iron, mg/l	328	310
Sulfate, mg/l	1,768	1,100
Flow, cfs	0.628	0.58

Table XIII
Effect of Surface Mine Reclamation in Watershed RT 6-19

	Before Reclamation	First Eleven Months After Reclamation
pH (Median)	2.8	6.4
Acidity, mg/l, $CaCO_3$	576	5
Total Iron, mg/l	107	0.04
Sulfate, mg/l	726	12

Summary - Surface Mine Reclamation. One year has past since the surface mine reclamation was completed and six months since these areas were revegetated. The water quality in each of the watersheds, which were polluted primarily from surface mines, has shown improvement. However, in all cases, but RT 6-19, the water is still of very poor quality and has not recovered its natural condition. It was expected that the improvement in water quality would be slow. Although every effort was made to place the best material available on the surface of the reclamation area, the soil still had a low pH, high acidity and acid producing material. It will probably require a number of years for the acid materials in the backfills to leach out; and during this period the stream will recover slowly. The good grass cover established on the backfills will prevent erosion and the exposure of more acid producing material, thus the rate of improvement in the streams should increase during the coming year.

In those areas polluted by both underground and surface mine drainage, pollution from the underground mines should constitute the greater portion of the pollution load as the rate of discharge from the surface mines diminishes.

Water Diversion. The most difficult control measure to evaluate has been water diversion. Following the completion of water diversion projects, the flow of the stream to which the water was diverted should increase while the volume of underground mine discharge should decrease. A number of factors complicate an analysis of this nature. First, in order to compare a "before" and "after" condition, the hydrologic situation must be somewhat similar during the times comparative data are taken; e.g., the rainfall and antecedent moisture conditions. Second, continuous flow measurements are also desirable for evaluation. Continuous flow monitoring was established at the mouths of Grassy Run and Roaring Creek for this purpose. However, since only half of the mine was reclaimed, these stations lost their value. Flow determinations were made at the remaining sampling stations only when samples were collected (once a week or every other week).

A preliminary evaluation of the runoff from the reclaimed areas indicated that the streamflow has increased and thus less water is entering the mine. For example, in one watershed, which contains 227 acres of reclaimed surface mines, the instantaneous flow at the mouth of the stream after reclamation has increased severalfold over the flow before reclamation for a similar precipitation occurrence. A culvert which carried this stream without problem before reclamation has flooded a number of times since reclamation. A detailed water balance is being developed for each of the watersheds, which should provide a better proof that an increase in flow has occurred.

Underground mine discharges do not reflect changes of inflow immediately. Dye studies have shown that water flowing in one end of the underground mine at Elkins may take several months before it discharges. Thus, to determine a reduction in discharge will require an analysis of both the surface and underground flow patterns. A preliminary review of the underground mine discharges data revealed that insufficient information was available to draw conclusions as to whether water diversion had decreased the flow. Further studies of the hydrology of the area are being conducted to determine lag times within the mines and develop a water budget.

SUMMARY

The Federal Water Pollution Control Administration in cooperation with other federal agencies and the State of West Virginia conducted a project to demonstrate the effectiveness of mine sealing, surface mine reclamation, and water diversion on the preventing of acid mine drainage from coal mines. This paper reports on the effectiveness of these control measures during the first year following the completion of the reclamation.

Improvement in water quality from mine sealing and surface mine reclamation was predicated to be a slow process, probably taking several years, due partly to the accumulation of pyrite oxidation products within the mine that must be flushed out.

Reclaimed surface mines must be stablized with vegetative cover.

After one year the following conclusions can be drawn:

(1) A small mine sealed against air shows a reduced oxygen content and the water discharging from the mine shows improvement; however, the water quality is still very poor. If the current trend continues water quality will continue to improve.

(2) Surface mine reclamation in those areas where the mine drainage was predominantly from this source has improved the water quality. The water quality is improving slowly and the trend is that it will continue to improve.

(3) Evaluation of water diversion as a control method is difficult. A preliminary analysis indicates that streamflow has increased in those areas where water was diverted from the underground mine to the stream. Further analyses are being made to verify this finding. Whether a reduction in underground mine discharges is occurring due to water diversion has not bees established.

References

(1) Stream Pollution by Coal Mine Drainage in Appalachia, Federal Water Pollution Control Administration, Washington, D. C., 1967

(2) "Acid Mine Drainage," House Committee Print No. 18, 87th Congress, Second Session, U. S. Government Printing Office, Washington, D. C., 1962

(3) Porges, R., Van Den Berg, L. A., and Ballinger, D. G., "Re-Assessing an Old Problem-Acid Mine Drainage," Journal of the Sanitary Engineering Division, Proceedings of the American Society of Engineers, SA 1, February 1966

(4) Moebs, N. N., "Mine Air Sealing - A Progress Report," Second Symposium on Coal Mine Drainage Research, Mellon Institute, Pittsburgh, Pennsylvania, May 1968

(5) Shumate, K. S., and Smith, E. E., "Development of a Natural Laboratory for the Study of Acid Mine Drainage Production," Second Symposium on Coal Mine Drainage Research, Mellon Institute, Pittsburgh, Pennsylvania, May 1968

ACKNOWLEDGEMENT

This project was a cooperative effort between the Federal Water Pollution Control Administration, the State of West Virginia, and the following federal agencies: U. S. Bureau of Mines, U. S. Geological Survey, and U. S. Fish and Wildlife Service. Mr. Lowell A. Van Den Berg, FWPCA, was responsible for the development of the field activities for this project and the coordination of the activities of the various agencies.